THE UNIVERSITY OF ALBERTA

THE RELATIONSHIP OF BODY COMPOSITION AND MEASURES OF MAXIMAL AND SUBMAXIMAL WORK CAPACITY

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Relationship of Body Composition and Measures of Maximal and Sub Maximal Work Capacity" submitted by Susan E. Neill in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

The purpose of this study was to investigate the relationship of estimates of body composition and measures of maximal and submaximal work capacity. Twenty-four male and twenty-four female subjects enrolled in the first year Physical Education and Recreation professional programs at the University of Alberta performed four tests of work capacity - the Mitchell, Sproule and Chapman, the Astrand, the Sjostrand and the Gradational Step test. Body composition was estimated by the densitometric method. Subsidiary problems investigated the differences in male and female subjects with respect to the relationship of body composition and work capacity.

Pearson product-moment correlation coefficients were calculated between each of the work capacity measures and body composition estimates and were tested for significance at the .05 level. There was a significant relationship between all tests of work capacity and both total weight and fat free body weight for both male and female subjects. The results of each test of work capacity were correlated against both total body weight and fat free body weight and the significance of the difference of the correlations tested. There was no significant difference in the relationship of any of the tests of work capacity with total body weight and fat free body weight.

The correlations of body composition and work capacity for males were compared with those derived for females. There was a significant difference between male and female subjects with respect to the relationship of percent fat and the Astrand test and fat free body weight and the

Mitchell, Sproule and Chapman results at the .05 level.

On the basis of the results of this study, it was concluded that work capacity expressed per kilogram of total body weight is probably as good a reference standard as work capacity per kilogram of fat free body weight.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

The ability of the body to perform muscular work is dependent upon the capacity of the cardiovascular system to supply oxygen to the active tissues (20). Many factors influence the ultimate work output - one of these being the composition of the body performing the work.

Not all of the tissues of the body influence the physical performance or the oxygen uptake. It is known that fat, for example, has a metabolism but little is known about the extraction of oxygen by the fatty tissues (46, 11). Fat is considered to be relatively inert (36). It follows then, that the remainder, or the fat free portion of the body is responsible for oxygen uptake. When discussing the oxygen uptake of the body, the body components may be divided into two compartments - fat and fat free (11). On the assumption that fat utilizes little oxygen, the oxygen uptake may be accredited to the fat free portion.

Although fat itself does not utilize oxygen, it cannot be denied that it does increase the total oxygen cost because of the extra load which does not contribute to performance (13). Excess fat may lower the maximal performance level and increase the energy expenditure for a given level of submaximal work. It is important to know the effect of the amount of fat and the amount of fat free tissue on the capacity of the body for maximal and submaximal work.

The Problem

The purpose of this study was to investigate the relationship of body composition and measures of maximal and submaximal work capacity.

Sub-problems

The following comparisons between male and female subjects were made:

1. The relationship of fat free body weight and total body weight to maximal oxygen uptake.

2. The relationship of fat free body weight and total body weight to Physical Work Capacity 170 (PWC 170).

Hypotheses

The following null hypotheses were investigated:

1. No relationship exists between maximal oxygen uptake and
   a) fat free body weight
   b) total body weight
   c) per cent fat

2. No relationship exists between Physical Work Capacity 170 and
   a) fat free body weight
   b) total body weight
   c) per cent fat

3. No significant difference exists in the relationship of maximal oxygen uptake and fat free body weight and total body weight in male and female subjects.

4. No significant difference exists in the relationship of PWC 170 and fat free body weight and total body weight in male and female subjects.

Need for the Study

Few studies examine the relationship of submaximal work capacity and estimates of body composition. Since some submaximal tests may be used to predict maximal work capacity, the relationship of body composition and maximal and submaximal work capacity should be investigated.

Limitations

The following were limitations of the study:

1. Several investigators were involved in the administration of the test items.

2. The formula devised by Brozek and Keys for the estimation of body fat is based on measures of the body composition of men. This formula was used in this study to estimate the fat content of women as well as men.

3. Temperature and humidity within the laboratory were not controlled.

4. Residual volumes were not measured directly but were estimated from a knowledge of vital capacity.

Delimitations

1. The subjects were first year students enrolled in the first year Physical Education and Recreation professional programs at the University of Alberta during the 1967-1968 University year.

2. The body was discussed in terms of two components only - fat and fat free. A further breakdown of components would result in a more accurate determination of unit body composition.

Definition of Terms

Maximal Oxygen Uptake. Maximal oxygen uptake is the maximum amount of oxygen that can be supplied to and utilized by the tissues for aerobic energy production.

Physical Work Capacity 170. Physical Work Capacity 170 is a measure of the amount of work that an individual can achieve at a heart rate of one hundred and seventy beats per minute.

Densitometry. Densitometry is a method of determining body density by the use of underwater weighing apparatus. The calculations are based on the formula -

$$D_b = \frac{M_a}{M_a - M_w}$$

where D_b is the density of the body

M_a is the mass of the subject in air

M_w is the mass of the subject in water

Fat Free Body Weight. Fat free body weight is the remaining weight of the body when the fat weight is subtracted from the total body weight.

Density. Density is the mass of a body per unit volume.

Total Body Fat. Total body fat is the amount of fat within the body as estimated by the formula:

$$f = \frac{4.570}{D_b} - 4.142$$

where D_b the density of the body.

f is the total body fat expressed as a fraction of unity or a percentage of total body weight.

Residual Volume. Residual volume is the volume of air in litres remaining in the lungs at the end of forced expiration.

Vital Capacity. Vital capacity is the volume of air in litres that can be expired from the lungs at the end of maximal inspiration.

Healthy Subject. A healthy subject is one who has passed the medical examination required before acceptance into the University of Alberta.

Maximal Work. Maximal work is that which causes the subject to reach exhaustion or maximal oxygen uptake.

Submaximal Work. Submaximal work is that which the subject is able to perform without reaching exhaustion or maximal oxygen uptake.

CHAPTER II

REVIEW OF THE LITERATURE

Maximal and submaximal work capacity have been the topic of many studies. A brief summary of several of these studies will be reported in this chapter as well as the relevant literature concerning body composition.

Maximal Work Capacity

Maximal work capacity is generally expressed in terms of maximal oxygen uptake or maximal heart rate at a known level of work.

The three most frequently used tests of maximal work capacity are the Mitchell, Sproule and Chapman (37), the Taylor, Buskirk and Henschel (49), and the Astrand (1). Glassford, Baycroft, Sedgwick and Macnab (24), using twenty-four healthy male subjects at the University of Alberta found the Taylor, Buskirk and Henschel test to yield the highest maximal oxygen uptake values. Because this test must be executed over a period of several days, it is not always practical to use. The Mitchell, Sproule and Chapman test yielded the second highest values and the Astrand the third.

Studies Concerning Maximal Work Capacity. Studies reveal relatively consistant values for maximal oxygen uptake of subjects of the same range of age and physical condition.

Mitchell, Sproule and Chapman (37), administered a maximal treadmill test to 65 normal men aged 20 to 29 years. The maximal oxygen uptake was found to be $3.37 \pm .51$ litres per minute. Buskirk and Taylor (13) found a similar value for 59 young men aged 18 to 29 years. Their mean maximal oxygen uptake was $3.44 \pm .046$ litres per minute.

Submaximal Work Capacity

Physiologists agree that maximal oxygen uptake is the best single predictor of a subject's ability to perform exhausting work (13). However tests requiring the subject to work to his maximum are not always practical in terms of time, equipment and physical state of the subject.

The Sjostrand PWC 170 test (45) was developed in answer to the need of a test of work capacity that could be used for unhealthy as well as healthy subjects of all ages. The object of the test is to measure the amount of work that the subject can perform at a heart rate of 170 beats per minute.

Step tests, in the past, have been used to measure submaximal work capacity but have not been considered valid measures of maximal work capacity (47). Recently, attempts have been made to develop a step test that could be used to estimate maximal performance (20, 39). These tests increase work load by increasing stepping rate.

The gradational step test used in this study was developed to simulate the principle and procedures of the Sjostrand PWC 170 test.

Methods of Determining Body Density and Fat Content

Behnke et al. (4) in 1942 were the first to use specific gravity as an indicator of body fat in man. On the premise that the relatively low specific gravity of fat makes the measurement of body specific gravity a valid measure for the estimation of fat content of the body, they discovered, by the use of the water displacement technique, that the mean density of 99 healthy male subjects in military service was 1.0684. The calculation of body density is outlined in a paper by Lim and Luft (30).

Rathbun and Pace (42), in 1945, found the density of 50 male and female guinea pigs to be 1.021 to 1.096. The following formula was derived for the estimation of per cent human fat on the basis of the data obtained for the fat of guinea pigs and its similarity to human fat.

$$\%F = 100 \quad \frac{5.548}{S.G.} - 5.044$$

Specific gravity (S.G.) in this case is defined as the weight of the subject in air divided by his weight in water subtracted from his weight in water.

In 1953, Brozek et al. (11) outlined a method for estimating fat content from body density. At this time, they constructed the hypothetical Reference Man on the basis of values obtained from 25 healthy men of average age 25 years. The Reference Man has a body density of 1.0629 and a fat content of 14 per cent of gross body weight. The following formula for the estimation of fat content was derived from values of the Reference Man.

$$f_b = \frac{4.201}{D_b} - 3.813$$

where f_b is the total body fat expressed as a fraction of unity.

D_b is the body density.

In 1963, Brozek (8) presented a paper in which the Minnesota Reference Man was replaced by the Minnesota Reference Body. The Reference Body was derived from measures of three male cadavers and has a body density of 1.063. The fat content is 15.3 per cent. From the Reference Body, the following equation evolved:

$$f_b = \frac{4.570}{D_b} - 4.142$$

where f_b is the total body fat

D_b is the body density.

Brozek says of this formula:

> This alters the amount of fat corresponding to a given body density. However, the difference resulting from the substitution of the new value for the fat content and body density is small. The important advance consists of replacing the assumed by the empirically determined fat content of the Reference Body. The gain is an increase in validity rather than precision (8).

To this date, the density of the fat free body weight of women is undetermined. Brozek states that "We do not know the density of the fat free mass of the female; it is probably somewhat lower than the male. Using a single formula is at present a reasonable approximation (12)."

Inspiration Versus Expiration During Underwater Weighing.

Several studies have attempted to determine the effect of the amount of air within the lungs at the time of underwater weighing.

Howell et al. (27) tested 135 average males of age range 20 to 29 years for buoyancy under three conditions of lung inflation. The underwater weight was taken at forced inspiration, normal inspiration and forced expiration. Two readings at each condition produced reliabilities of .92, .32 and .87 respectively.

Welch et al. (51) determined the body density of 26 normal healthy males with a mean age of 24.9 $\pm$ 5.9 years using the underwater weighing technique. The underwater weight was taken at maximal expiration and one half maximal expiration. At maximal expiration, the mean density was 1.0559 grams per cubic centimeter and at half maximal expiration, the mean density value was 1.0576 grams per cubic centimeter, a significantly higher value. The authors state that a lung at one half maximal expiration is more susceptible to hydrostatic pressures and therefore recommend that underwater weight be taken at maximal expiration. They add that, in some cases, especially

in untrained subjects, it is preferable to take underwater weight at maximal inspiration in order to eliminate the psychological effect of an empty lung.

Yuhasz (56), Coyne (15) and Dempsey (18) recorded underwater weight at maximal inspiration. Sloan (46) recorded underwater weight at maximal expiration.

Determination of Residual Volume

Residual volume is the amount of air remaining in the lungs at the end of maximal expiration. Because the body is buoyed up by a force equal to the weight of the water replaced by the residual volume, the residual volume must be accounted for in the calculations.

Instead of measuring the residual volume, several investigators have made use of constant values for the residual volumes of all subjects. Yuhasz (56) has used the constant value of 1.45 litres for male subjects. Young (54) used the value of 1.022 litres for female subjects.

Coyne (15) and Dempsey (18) have used the helium dilution technique to measure residual volume directly. Dempsey recommends that the residual volume be measured while the subject is immersed. Behnke et al (5) found that, in measuring the residual volume on land and then underwater, the difference was not significant and would not influence the fat content by more than one per cent.

Craig and Ware (16), in studying the effect of submersion on the vital capacity and residual volume of 21 healthy males, found no significant difference between immersed and non-immersed readings for residual volumes but found that the vital capacity readings were significantly lower when the subjects were immersed.

Studies Reporting Body Composition Estimates

Many studies report body composition estimates. Several of the pertinent studies were reviewed.

Young et al. (55), using 94 females with a mean age of 20.36 years as subjects, found a mean fat weight of 28.69 per cent of total body weight. The investigators used the underwater weighing method of density determination and the formula of Rathbun and Pace.

The body composition of 35 females aged 19 to 35 years and 35 males aged 19 to 40 years was studied by von Dobeln (50). Using the densitometric method and the 1953 formula of Brozek and Keys, von Dobeln found that the average female body contained 20.3 per cent fat and had a density of 1.048 and the average male body contained 10.6 per cent fat and had a density of 1.072.

Sloan (46), using the 1963 formula of Brozek and Keys and the densitometric method found the mean body density of 50 young men aged 18 to 26 to be 1.0754. The mean percentage of fat was 10.8 per cent of the total body weight.

Buskirk and Taylor (13) estimated the body composition of 59 young men. Using the 1953 formula of Brozek and Keys, he calculated the mean percentage of fat in the body to be 13.9 and the mean density to be 1.0632.

Measures of Work Capacity and Body Composition

Maximal Oxygen Uptake. It is well known that maximal oxygen uptake varies with physical fitness (3). The higher the level of physical fitness, the greater is the possible maximal oxygen uptake of the body. There are, however, other factors which influence maximal oxygen uptake, one of these being body composition.

Many studies have reported a comparison of measures of maximal oxygen uptake expressed in terms of total body weight and fat free body weight.

Welch et al. (52) found a correlation of .59 between body weight in kilograms and maximal oxygen uptake and a correlation of .65 between fat free body weight and maximal oxygen uptake. The 28 young male subjects were tested by the Taylor, Buskirk and Henschel maximal treadmill test and the specific gravity technique of Pascale. Thirty-five per cent of the variations of maximal oxygen uptake were accounted for by total body weight and 41 per cent by fat free body weight.

Buskirk and Taylor (13), also using the Taylor, Buskirk and Henschel treadmill test, the underwater method of density determination and the 1953 formula of Brozek and Keys for the estimation of body fat, tested 59 men aged 18 to 29 years. The resulting correlations were .63 between body weight and maximal oxygen uptake and .85 between fat free body weight and maximal oxygen uptake. Fat free body weight was responsible for 72 per cent of the variation in maximal oxygen uptake.

Darwick (17), testing 28 college women aged 19 to 22 years, found a correlation of .64 between maximal oxygen uptake and both total body weight and fat free body weight.

Seltzer (43) measured the maximal oxygen uptake of 34 female subjects aged 20 to 38 years. The test consisted of a five minute run to exhaustion on the treadmill. The resulting correlation between maximal oxygen uptake and body weight in kilograms was .88.

Michael and Horvath (33), studying the work capacity of 30 college women aged 17 to 22 years found a correlation of .56 between body weight and maximal oxygen uptake. The subjects performed a continuous bicycle ride.

von Dobeln (50), examined the relationship between maximal oxygen uptake, body size and total hemoglobin in 33 male and 32 female subjects. A correlation of .76 was found between maximal oxygen uptake, and body weight minus adipose tissue to the 2/3 power.

Submaximal Work Capacity. The effects of body composition on submaximal performance were investigated by Miller and Blyth (36). Thirty healthy male subjects aged 19 to 28 years walked on a treadmill for 15 minutes at 5 miles per hour and at a 10 per cent grade. The correlation of oxygen uptake and body weight was .75 and of oxygen uptake and lean body mass was .67. The authors state that:

> 1. The metabolic cost of lifting the body is directly proportional to the gross body weight and the cost per unit of body weight is only slightly influenced by height and fat content.
> 2. Gross body weight is the best metabolic reference standard for expressing the cost of work involving lifting the body weight.

Thirty-one males aged 19 to 26 years were tested by Taylor (47) for both maximal and submaximal performance on a treadmill. During submaximal exercise, the correlation between body weight and oxygen uptake was .71. During maximal performance, the correlation between body weight and oxygen uptake was .43. Taylor concludes that submaximal exercise is chiefly a function of body weight while maximal exercise is not.

Buskirk and Taylor (13), in a previously mentioned study arrived at the following conclusions concerning oxygen uptake and body composition:

> 1. The presence of excess fat does not have any significant effect on the ability of the cardiovascular-respiratory system to deliver oxygen to the muscles under maximal conditions.
> 2. The obese man is under a handicap because of the extra load of fat which does not contribute to performance.

3. The excess fat does increase the oxygen cost and therefore the cardiovascular load during maximal work.
4. The presence of fat does not interfere with the overall maximal performance as measured by the maximal oxygen uptake test.

Reliability of Densitometry Technique. The reliability of the densitometric method is high. Durnin and Taylor (21) found that the error in a single measure in 90 per cent of the cases was $\pm$ .004 units.

Buskirk and Taylor (13) found the reliability of the densitometric method to be .95.

Gnaedinger et al (25) state that "underwater weighing is at present considered to be the most reliable method (for predicting body composition) for human beings."

CHAPTER III

METHODS AND PROCEDURE

Sample

The subjects were twenty-four healthy males and twenty-four healthy females randomly selected from the students enrolled in the first year of the Physical Education and Recreation professional programs at the University of Alberta, 1967-1968. Table I presents some of the characteristics of the subjects.

TABLE I

DESCRIPTION OF THE SUBJECTS

	NO.	AGE (years)	HEIGHT (inches)	WEIGHT (pounds)
Male	24	19.97	70.59	167.51
Female	24	18.67	65.22	130.61

Conditions of Testing

Each subject was asked to adhere to the following conditions of testing:

A. Work Capacity Tests

1. to participate in a short training session prior to testing in order to become familiar with each piece of apparatus and its operation.
2. to refrain from smoking, eating or exercising for at least two hours prior to each test.
3. to wear running shoes, shorts and some form of shirt.

B. Body Composition Estimates

1. to refrain from eating for at least two hours and if possible four hours before underwater weighing.

2. Male subjects wore their own bathing suits. Female subjects wore standardized nylon suits. No bathing caps were worn.

Order of Tests

The following tests of work capacity were performed by the subjects:

1. The Mitchell, Sproule and Chapman (test and retest)
2. The Astrand Bicycle Ergometer Test
3. The Sjostrand PWC 170 (test and retest)
4. The Gradational Step Test (test and retest)

Each subject initially performed the Mitchell, Sproule and Chapman test. The remaining tests were executed in random order. Tests and retests of the submaximal tests were conducted on consecutive days whenever possible. At least one day elapsed between a maximal test and the following test. In the test retest situation, the value of the second Mitchell, Sproule and Chapman test and the value of the first Sjostrand and Step Test were used in the final analysis. All tests of work capacity for each subject were completed within twenty days.

After the completion of all tests of work capacity, the subjects were weighed by the underwater method.

Testing Procedure

The Mitchell, Sproule and Chapman Test. The original test was modified to meet the needs of this study.

1. Prior to the test, the subject was fitted with a plastic triple J valve, rubber mouthpiece and head gear. Electrodes were placed at three sites - three inches below the right nipple, three inches below the left nipple and at the base of the left scapula, and were held in place by a rubber strap. Each electrode was coated

lightly with Redux electrode jelly. The electrode wires were connected to a Sanborn portable electrocardiograph.

2. As a warm up to the test, subjects walked for 10 minutes at 3 miles per hour at a ten per cent grade on a large motor driven treadmill.

3. The warm up and each subsequent exercise period was followed by a 10 minute rest period. Heart rate was recorded for the first 15 seconds after the termination of the exercise.

4. Following the rest period, male subjects began running at 6 miles per hour at a 7.5 per cent grade and female subjects at 6 miles per hour at 0 per cent grade. The duration of the run was 2.5 minutes. The head gear was worn throughout the run. The subject was instructed to insert the rubber mouthpiece and attach the noseclip for the final minute and thirty seconds of the run. Air was expired into 200 litre Douglas bags during the last minute of the run. Heart rate was recorded in the manner previously described.

5. During the ten minute rest period, expired air was analyzed for oxygen and carbon dioxide content. Per cent oxygen was measured by a Beckman E_2 Oxygen Analyzer and per cent carbon dioxide by a Godart Capnograph. The volume of air expired was measured by an American Volume Meter. Calculations were made on an Epic 3000 Monroe calculator.

6. The grade of the treadmill was increased 2.5 per cent for each of the subsequent runs for both male and female subjects. Speed remained constant at 6 miles per hour.

7. The subject continued the pattern of exercise followed by rest until his oxygen uptake decreased or else he reached exhaustion.

<u>The Astrand Bicycle Ergometer Test</u>. The original was modified slightly to meet the needs of the study.

1. The seat of the bicycle was adjusted for each subject so that the lower pedal rested directly beneath the longitudinal arch of the foot and the knee was slightly bent.

2. The head gear, gas analysis equipment and electrocardiograph were the same as that described for the Mitchell, Sproule and Chapman Test. Prior to the test the head gear was fitted and the electrodes placed.

3. The initial work load was set at 150 KpM for female subjects and 450 KpM for male subjects. The duration of the exercise bout was 4 minutes at a speed of 50 pedal revolutions per minute. An electric metronome assisted the subjects in keeping a constant speed. The first exercise period was used as a warm up and expired air was not collected.

4. Each period of exercise was followed by a 5 minute rest.

5. The first work load of the actual test was set at 450 KpM for females and 750 KpM for males. The subjects began pedalling and after 2 minutes and 45 seconds of the exercise were instructed to insert the mouthpiece and attach the noseclip. Expired air was collected during the final minute of exercise.

6. Heart rate and the number of pedal revolutions were recorded at the end of the exercise bout.

7. Gas analysis calculations were made during the 5 minute rest period between exercise bouts.

8. The work load of each subsequent exercise period was increased by 150 KpM for both male and female subjects.

9. The sequence of exercise periods followed by rest periods was continued until either the oxygen uptake of the subjects decreased or the subject reached exhaustion.

The Sjostrand PWC 170 Test. The Sjostrand PWC 170 test is a test of submaximal work capacity, the score expressed as the work load accomplished at a heart rate of 170 beats per minute.

1. The test was performed on a Monark Bicycle Ergometer. The electrode sites were the same as those chosen for the Mitchell, Sproule and Chapman test. Heart rates were recorded on a portable Sanborn electrocardiograph.

2. Pre-exercise heart rate was recorded.

3. Subjects pedalled a total of 12 minutes at three increasingly difficult work loads and at a speed of 60 pedal revolutions per minute. Heart rate was recorded during the last 15 seconds of each minute and pedal revolutions were recorded at the end of each minute.

4. The initial load on the bicycle was set at 150 KpM for females and 450 KpM for males and was increased at the end of the fourth and eighth minute of exercise. The three work loads were set to illicit the following heart rate responses: 115-130, 135-155, and 160-180 beats per minute respectively. The second and third work load settings were dependent upon the heart rates at the end of the fourth and eighth minutes.

5. The heart rate at the end of the fourth minute was plotted against that particular work load and the regression line was drawn and extrapolated or interpolated to a heart rate of 170 beats per minute. The subject's score was the work that he would be able to produce at a steady state heart rate of 170 beats per minute.

The Gradational Step Test. The gradational step test is a submaximal test and was developed to simulate the principle and procedures

of the Sjostrand PWC 170 test. The score is expressed as the work load achieved at a heart rate of 170 beats per minute.

The variable height step ergometer consisted of three permanent levels of heights 10, 25 and 40 centimeters respectively. In addition, two sliding shelves of 5 centimeters could be added to each of the three levels.

1. The electrodes were placed as described for the Mitchell, Sproule and Chapman test. Pre-exercise heart rate was recorded.

2. The test consisted of three 4 minute work bouts at three increasingly difficult step heights which were designed to produce heart rates of 115-130, 135-155 and 160-180 beats per minute respectively. The subjects stepped at a rate of 28 steps per minute throughout the test. The rate of stepping was kept constant by the use of an electric metronome.

3. Female subjects began stepping at a height of 15 centimeters and male subjects at a height of 25 centimeters.

4. Heart rate was recorded during the last 15 seconds of each minute. Step increments for the second and third levels were based on the heart rate response at the end of the fourth and eighth minute.

5. The heart rate at the end of the fourth minute of each work level was plotted against that particular work load and the regression line drawn and extrapolated or interpolated to a heart rate of 170 beats per minute. The subject's score was the work in KgM he would be able to accomplish at a steady state heart of 170 beats per minute.

Densitometry. A large tank constructed of 16 gauge galvanized steel plate, 72 inches in height and 48 inches in diameter was used for underwater weighing. The tank was surrounded by a platform 18 inches in width. Within the tank, an aluminum chair was suspended from

a load cell which was suspended by a cable from the ceiling. The load cell was connected to a Sargent Recorder (model SR).

The temperature of the water in the tank was recorded daily and was kept fairly constant by a regulator attached to the faucet.

1. The Sargent recorder was calibrated to give a reading of zero for the weight of the chair and the cable under water. A steel weight of true weight 17.5 pounds represented 70 units on the chart paper of the recorder. Any deflection above or within the 70 unit range was accredited to the weight of the subject seated in the chair with his lungs fully inflated. The weight, corresponding to the number of units of deflection as registered on the Sargent recorder, was recorded as the uncorrected weight of the subject in water.

2. The subject, dressed in swim suit, was weighed on land.

3. After climbing into the tank, the subject sat in the aluminum chair with his head remaining out of the water. The 17.5 pound weight was placed on his thighs.

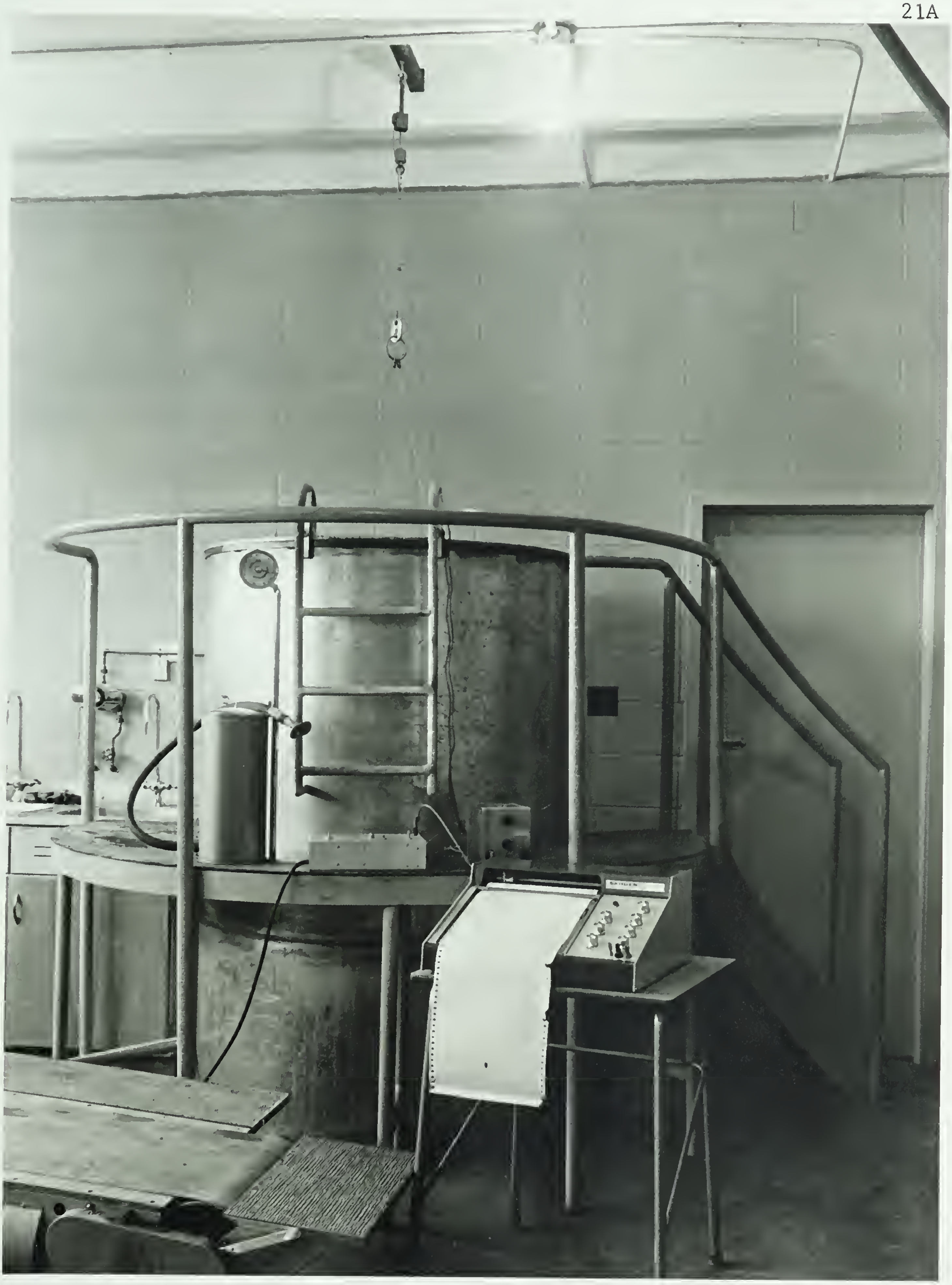
4. Vital capacity was measured using a Collin's Vitalometer. The highest of three readings was recorded.

5. Air bubbles were brushed from the subject's body.

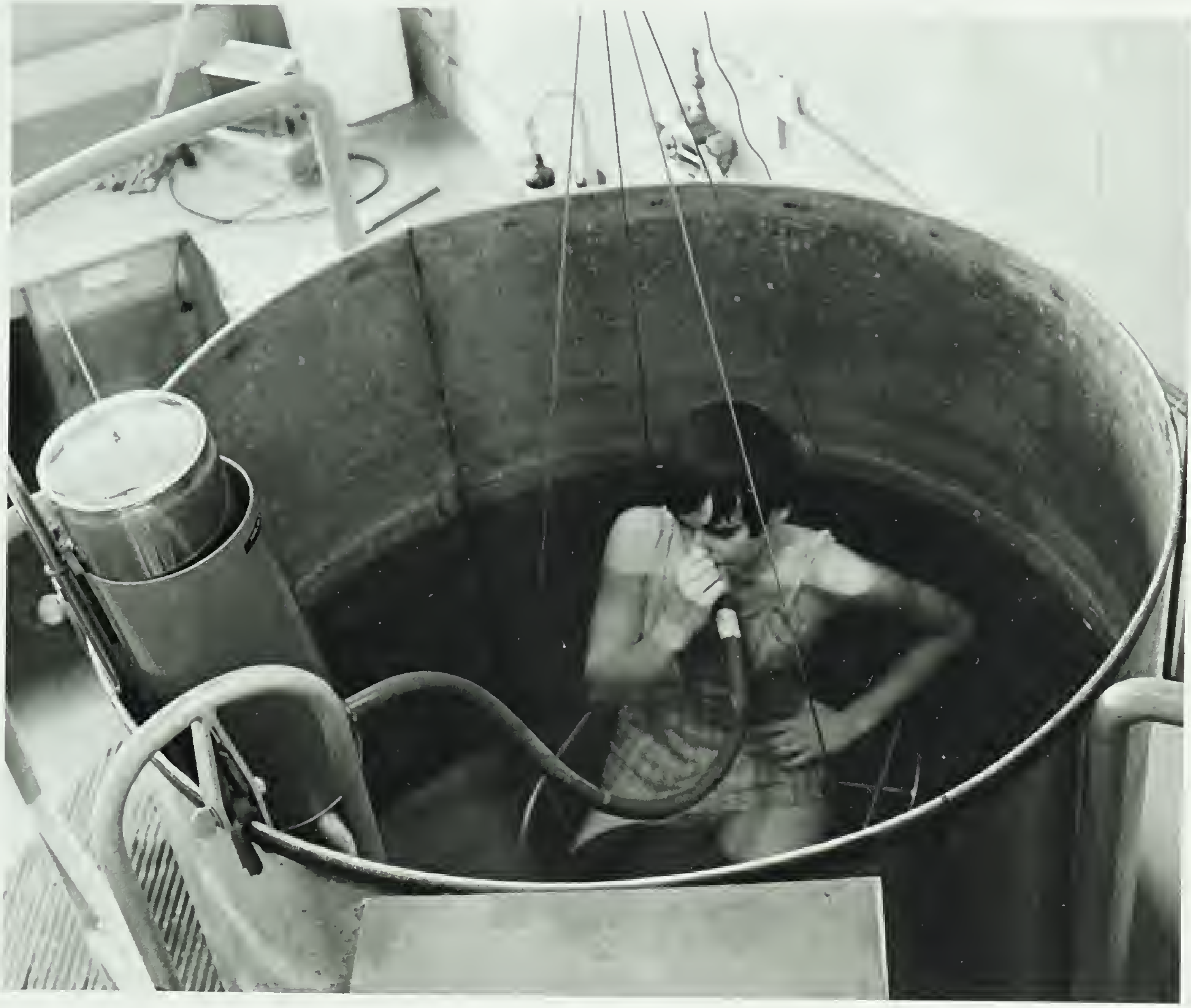
6. The subject was instructed to inspire maximally, pinch his nose closed and lean forward until completely submerged. Bubbles were brushed from the subject's hair.

The above procedure was repeated three times and the lowest reading was used in the calculation.

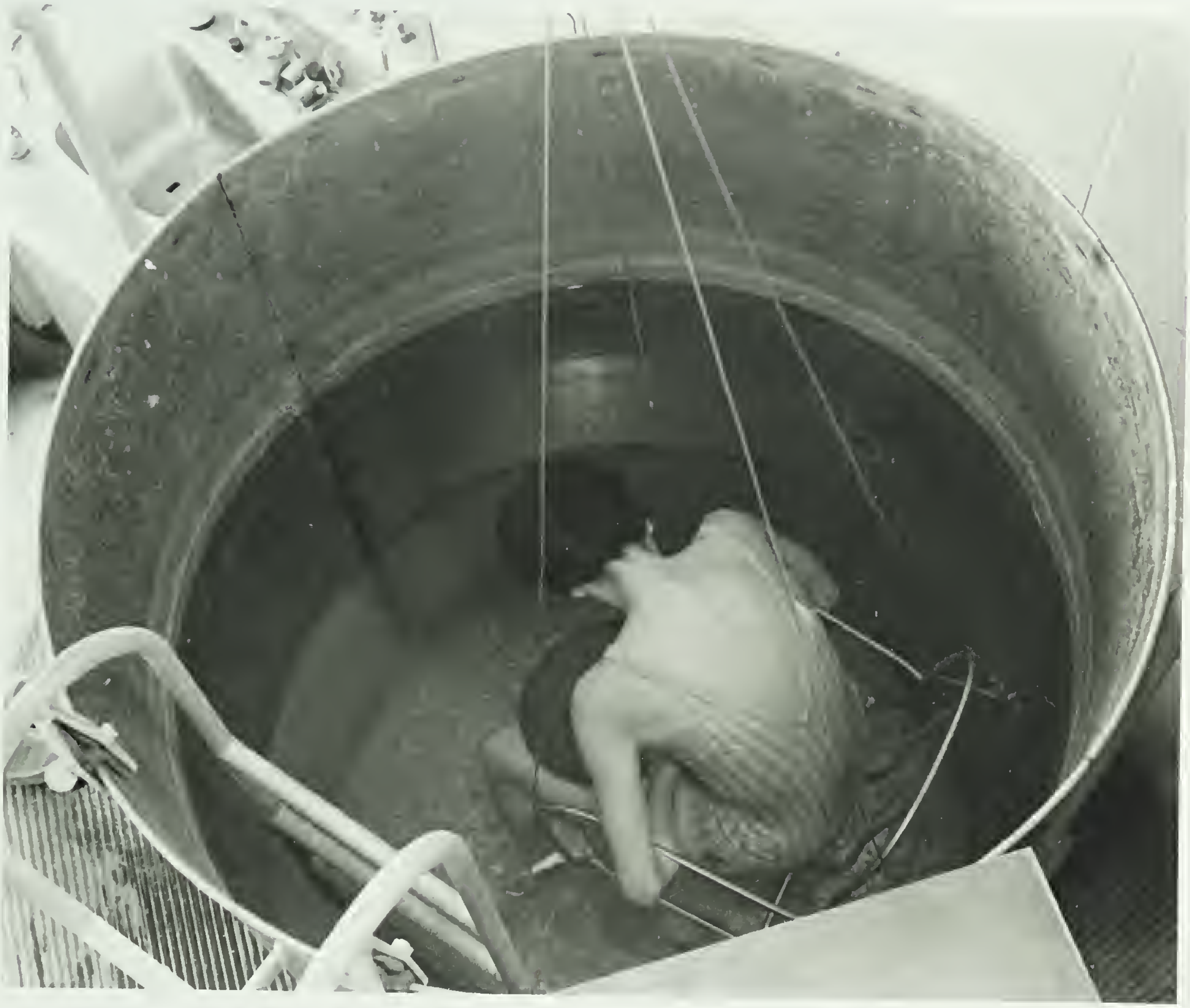
Mathematical Calculations for Body Density Determination. The determination of density is based on Archimedes Principle which states that a body in water is buoyed up by a force equal to the weight of the water displaced by the body.



I UNDERWATER WEIGHING APPARATUS



II MEASUREMENT OF VITAL CAPACITY



III UNDERWATER WEIGHING - MAXIMAL INSPIRATION

The weight of the subject was recorded on land and underwater and was substituted into the formula:

$$D_b = \frac{M_a}{M_a - M_w}$$

where D_b is the density of the body

M_a is the weight of the body on land

M_w is the weight of the body in water

The above formula was corrected for residual volume, vital capacity and gastro-intestinal gas. The formula corrected for gases becomes:

$$D_b = \frac{M_a}{M_a - M_w - .0362\ (\ VC + RV + VGI\ )} \times D_w$$

where D_b is the density of the body

M_a is the weight of the subject on land

M_w is the weight of the subject in water

VC is the vital capacity

RV is the residual volume

VGI is the gas in the gastro-intestinal tract

D_w is the density of water

One cubic inch of air at STP weighs .0362 pounds.

Estimation of Body Fat. The formula of Brozek and Keys (1963) was used to estimate the amount of fat within the body. Density values as calculated above were substituted into the formula:

$$f_b = \frac{4.570}{D_b} - 4.142$$

where f_b is the total body fat expressed as a fraction of unity

D_b is the density of the body

Lung Volumes.

A. Vital Capacity

Vital capacity was measured at the time of underwater weighing.

The subject inspired maximally and then expired maximally into a Collins Vitalometer. The highest of three readings was recorded.

B. Residual Volume

Residual volume was estimated as 25 per cent of the vital capacity (17).

C. Gastro-intestinal Gas

Gastro-intestinal gas was considered as a constant value of 115 ml. in all subjects (18).

Treatment of Results. The data were analyzed by the computor.

1. The mean, standard deviation and range of all variables were calculated.

2. The degree of relationship between measures of body composition and work capacity was described using a Pearson Product Moment Correlation Coefficient (21). The correlation coefficient was tested for significance using a t test for significance of a correlation.

3. The significance of difference between the correlation coefficients was tested using Fisher's Z_r transformation.

4. The .05 level of significance was accepted for all hypotheses.

CHAPTER IV

RESULTS AND DISCUSSION

Age, Height and Weight of the Subjects

The sample consisted of 24 males and 24 females randomly selected from the first year of the Physical Education and Recreation program at the University of Alberta. Table II presents the mean, range and standard deviations of the age, height and weight of the subjects.

TABLE II

AGE, HEIGHT AND WEIGHT OF SUBJECTS

	Mean	Range	Standard Deviation
Age (Yr.)			
Male	19.97	18.33 - 22.44	1.16
Female	18.67	17.92 - 20.42	.63
Height (In.)			
Male	70.59	65.50 - 75	2.39
Female	65.28	60.50 - 68.50	2.10
Weight (Lb.)			
Male	167.51	131. -204	18.98
Female	130.61	107.25 -150.50	12.93
Weight (Kg.)			
Male	74.59	55.11 - 92.53	9.54
Female	59.24	48.65 - 68.27	5.87

Results of Work Capacity Tests

The Mitchell, Sproule and Chapman Test. The subjects completed two trials of the Mitchell, Sproule and Chapman test and the score of the second test was used in the analysis. Table III presents a summary of maximal oxygen uptake values in litres per minute, milliliters per minute per kilogram of total body weight and milliliters per minute per kilogram of fat free body weight for male and female subjects.

TABLE III

MAXIMAL OXYGEN UPTAKE AS DETERMINED BY THE MITCHELL, SPROULE AND CHAPMAN TEST II

	Mean	Range	Standard Deviation
Litres/min.			
Male	3.94	2.82 - 5.51	.65
Female	2.33	1.62 - 1.63	.42
Ml/min/Kg			
Male	51.85	.02 - .04	5.56
Female	39.12	.02 - .03	4.87
Ml/min/Kgffbw			
Male	59.56		
Female	51.55		

The Astrand Bicycle Ergometer Test. The mean, range and standard deviation of the Astrand bicycle ergometer test are given in Table IV. Maximal oxygen uptake is expressed in litres per minute, milliliters per minute per kilogram of total body weight and milliliters per minute per kilogram of fat free body weight for male and female subjects.

TABLE IV

MAXIMAL OXYGEN UPTAKE AS DETERMINED BY THE ASTRAND BICYCLE ERGOMETER TEST

	Mean	Range	Standard Deviation
Litres/min.			
Male	3.52	2.06 - 5.11	.61
Female	2.12	1.17 - 2.94	.41
Ml./min./Kg.			
Male	46.47	.03 - .07	6.25
Female	35.67	.02 - .05	5.59
Ml./min./Kgffbw			
Male	53.12		
Female	46.92		

Results of Submaximal Work Capacity Tests

The Sjostrand PWC 170 Test. Each subject completed two trials of the Sjostrand PWC 170 Test. The score of the first test was used in the analysis. The subject's score on the Sjostrand test is the work he would be able to produce at a heart rate of 170 beats per minute in kilopond-metres (KpM). The mean, range and standard deviation of the Sjostrand scores are presented in Table V.

TABLE V

PHYSICAL WORK CAPACITY 170 AS DETERMINED BY
THE SJOSTRAND PWC 170 TEST I

	Mean	Range	Standard Deviation
KpM/min.			
Male	1345.11	788.63 - 1766.36	269.43
Female	769.32	460.52 - 1062.58	158.19
KpM/min./Kg			
Male	18.002	10.29 - 26.59	3.44
Female	12.91	8.90 - 17.31	2.52
KpM/min/Kgffbw.			
Male	20.71	11.93 - 31.64	3.97
Female	16.90	10.99 - 11.59	2.93

The Gradational Step Test. Two trials of the gradational step test were performed by each subject. The score of the first test was used in the analysis. The subject's score is the work in kilogram-metres that he would be able to perform at a heart rate of 170 beats per minute. The mean, range and standard deviation of the scores are presented in Table VI.

TABLE VI

PHYSICAL WORK CAPACITY 170 AS DETERMINED BY THE GRADATIONAL STEP TEST I

	Mean	Range	Standard Deviation
KgM/Min.			
Male	885.85	534.61 - 1397.85	186.18
Female	488.89	340.61 - 706.25	109.38
KgM/Min/Kg.			
Male	11.64	8.67 - 15.11	1.89
Female	8.24	5.75 - 11.34	1.54
KgM/Min/Kgffbw			
Male	13.41	9.96 - 19.23	2.27
Female	10.79	7.72 - 14.25	1.79

Body Composition Estimates

From the measurements made during underwater weighing, estimates of body composition were made. Table VII shows the mean, range and standard deviation of total body weight, fat free body weight, and per cent fat for male and female subjects.

TABLE VII

ESTIMATES OF WEIGHTS OF BODY COMPOSITION COMPONENTS OF MALE AND FEMALE SUBJECTS

		Mean	Range	Standard Deviation
Total Body Wt.				
Male	- lb.	167.51	131.0 - 204.0	19.20
	Kg.	75.98	59.42 - 92.53	8.71
Female	- lb.	130.61	107.50 - 150.50	12.91
	Kg.	59.25	48.76 - 68.27	5.86
Fat Free Body Wt.				
Male	- lb.	145.88	109.15 - 177.98	18.91
	Kg.	66.17	49.51 - 80.73	8.58
Female	- lb.	99.65	78.01 - 121.27	11.89
	Kg.	45.20	35.387- 55.01	5.40
Per Cent Fat				
Male		12.74	5.33 - 21.45	4.32
Female		23.43	17.91 - 33.13	4.46

Body Density. From the measurements made during underwater weighing, the body density was calculated. The mean, range and standard deviation of the body density is given in Table VIII for male and female subjects.

TABLE VIII

BODY DENSITY OF MALE AND FEMALE SUBJECTS

	Mean	Range	Standard Deviation
Male	1.07	1.05 - 1.09	.02
Female	1.04	1.02 - 1.06	.01

Body Composition and Work Capacity

The Pearson Product Moment Correlation technique was used to estimate the relationship between tests of work capacity and measures of body composition. The tests of work capacity were the Mitchell, Sproule and Chapman (expressed in litres per minute), the Astrand Bicycle Ergometer test (expressed in litres per minute), the Sjostrand test (expressed in KpM per minute) and the Gradational Step test (expressed in KgM per minute). Body composition was expressed in kilograms of total body weight, kilograms of fat free body weight and per cent fat.

Female Scores. The correlation coefficients between work capacity and body composition for female subjects are expressed in Table IX. The scores of the Mitchell, Sproule and Chapman test correlated .72 with total body weight, .84 with fat free body weight and .37 with per cent fat. The Astrand scores correlated .59 with total body weight, .63 with fat free body weight and -.23 with per cent fat. Sjostrand test scores correlated .44 with total body weight, .60 with fat free body weight and -.41 with per cent fat. The scores of the step test correlated .52 with total body weight, .66 with fat free body weight and -.44 with per cent fat.

TABLE IX

CORRELATIONS OF BODY COMPOSITION ESTIMATES AND MEASURES OF WORK CAPACITY FOR FEMALE SUBJECTS

Test	Total Wt. (Kg.)	FFBW (Kg.)	% Fat
MSC2	.72*	.84*	-.37
Astrand	.59*	.63*	-.23
Sjostrand I	.44*	.60*	-.41*
Step I	.52*	.66*	-.44*

* Significant at the .05 level

Male Scores. Correlations between work capacity and body composition measures for male subjects are presented in Table X. The scores of the Mitchell, Sproule and Chapman test correlated .74 with total body weight, .76 with fat free body weight and -.25 with per cent fat. Scores of the Astrand test correlated .61 with total body weight, .69 with fat free body weight and -.42 with per cent fat. The Sjostrand test scores correlated .46 with total body weight, .47 with fat free body weight and -.52 with per cent fat. The step test results correlated .62 with total body weight, .56 with fat free body weight and -.05 with per cent fat.

TABLE X

CORRELATIONS OF BODY COMPOSITION ESTIMATES AND MEASURES OF WORK CAPACITY FOR MALE SUBJECTS

Test	Total Wt. (Kg.)	FFBW (Kg.)	% Fat
MSC2	.74*	.76*	-.25
Astrand	.61*	.69*	-.42*
Sjostrand I	.46*	.47*	-.52*
Step I	.62*	.56*	-.05

* Significant at the .05 level

Table XI shows the correlation coefficients between body composition and work capacity for female subjects if the means of the test-retest scores are used instead of the scores of the second Mitchell, Sproule and Chapman test and the first Sjostrand and step test. Table XII gives the correlations for male subjects.

TABLE XI

CORRELATIONS OF BODY COMPOSITION AND WORK CAPACITY FOR FEMALE SUBJECTS USING MEAN SCORES OF WORK CAPACITY TESTS

	TBW	FFBW	% Fat
MSC-Mean L/min.	.69*	.77*	-.29
Sjost.-Mean KpM	.53*	.68*	-.44*
Step-Mean KgM	.51*	.63*	-.35

* Significant at the .05 level

TABLE XII

CORRELATIONS OF BODY COMPOSITION AND WORK CAPACITY FOR MALE SUBJECTS USING MEAN SCORES OF WORK CAPACITY TESTS

	TBW	FFBW	% Fat
MSC-Mean L/min.	.72*	.76*	-.32
Sjost.-Mean KpM	.49*	.52*	-.21
Step-Mean KgM	.60*	.55*	-.05

* Significant at the .05 level

Statistical Analysis

Pearson Product Moment Correlation Coefficient (r). Correlation coefficients were calculated between body composition estimates and measures of work capacity using the formula:

$$r = \frac{N\Sigma XY - \Sigma X\Sigma Y}{\sqrt{[N\Sigma X^1 - (\Sigma X)^2][N\Sigma Y^2 - (\Sigma Y)^2]}}$$

The calculated correlation coefficients are summarized in Tables IX, X, XI, and XII.

Variance Interpretation of a Correlation Coefficient. The square of a correlation coefficient (r^2) may be interpreted as the ratio of the two variances, the variance of the predicted values of Y on X divided by the variance of the observed values of X on Y. (22)

Applying this knowledge to the correlation coefficients calculated between body composition and work capacity, the variance in work capacity which may be predicted from a knowledge of the components of the body may be estimated. Each of the correlation coefficients was squared.

The variance interpretation of the correlation coefficients, as reported in Table XIII, indicates that 55.10 per cent of the variability in maximal oxygen uptake as determined by the Mitchell, Sproule and Chapman test, may be accounted for by variation in total body weight; 57.76 per cent by the variation in the fat free body weight and 6.20 per cent by the variation in per cent fat in the male subjects. The remaining correlation coefficients may be similarly interpreted.

TABLE XIII

VARIANCE INTERPRETATION OF CORRELATION COEFFICIENTS

	Total Weight			Fat Free Weight			Per Cent Fat		
	r	r^2	%	r	r^2	%	r	r^2	%
MSC2									
Male	.742	.551	55.10	.760	.5776	57.76	-.249	.062	6.20
Female	.721	.5198	51.98	.840	.7056	70.56	-.368	.1354	13.54
Astrand									
Male	.605	.3660	36.60	.687	.4719	47.19	-.419	.1755	17.55
Female	.590	.3481	34.81	.629	.3956	39.56	-.225	.0506	5.06
Sjost.I									
Male	.464	.2152	21.52	.468	.2190	21.90	-.519	.2693	26.93
Female	.440	.1936	19.36	.598	.3576	35.76	-.412	.1697	16.97
Step I									
Male	.617	.3806	38.06	.564	.3180	31.80	-.051	.0026	.26
Female	.520	.2704	27.04	.660	.4356	43.56	-.44	.1936	19.36

Significance of Correlation Coefficients. The correlation coefficients between measures of work capacity and estimates of body composition were tested for significance of difference from zero using the

t test for significance of a correlation (22). The required t is calculated by the formula:

$$t = r\sqrt{\frac{N-2}{1-r^2}}$$

For 22 degrees of freedom, a calculated t of 2.074 is required for significance at the .05 level.

For female subjects, total body weight correlated significantly with scores of the Mitchell, Sproule and Chapman II test, the Astrand test, the Sjostrand I test, and the Step I test. Fat free body weight correlated significantly with the Mitchell, Sproule and Chapman II tests, the Astrand, the Sjostrand I test and the Step I test. Per cent fat correlated significantly with the Sjostrand I and the Step I test results.

For male subjects, total body weight and fat free body weight both correlated significantly with the Mitchell, Sproule and Chapman II test, the Astrand test, the Sjostrand I test and the Step I test scores. Per cent fat correlated significantly with the Astrand and the Sjostrand I test scores.

Significance of Difference of Correlation Coefficients. The results of each test of work capacity were correlated with total body weight and fat free body weight and the significance of the difference of the correlation coefficients tested using a t test of the significance of the difference of correlation coefficients of correlated samples. The following formula was used:

$$t = \frac{(r_{12} - r_{13})\sqrt{(N-3)\ (1+r_{23})}}{\sqrt{2(1-r_{12}^2 - r_{13}^2 - r_{23}^2 + 2r_{12}\ r_{13}\ r_{23})}}$$

For 21 degrees of freedom, a t of 2.080 was required for significance at the .05 level. Table XIV presents the calculated t's for the correlation coefficients.

There was no significant difference in the relationship of work capacity (at either the maximal or submaximal levels) and total body weight and fat free body weight for either male or female subjects

TABLE XIV

SIGNIFICANCE OF THE DIFFERENCE OF CORRELATION COEFFICIENTS

Test	TBW	FFBW	t
MSC2			
Male	.742	.760	.3126
Female	.721	.840	1.8622
Astrand			
Male	.605	.687	1.2584
Female	.590	.629	.4297
Sjostrand I			
Male	.464	.468	.0504
Female	.440	.598	1.6949
Step I			
Male	.617	.564	.7479
Female	.520	.660	1.5901

Comparison of the Relationship of Body Composition and Work Capacity in Male and Female Subjects. The significance of the difference in the relationship of estimates of body composition and the various work capacity results for male and female subjects were tested using Fisher's Z_r transformation. The calculated Z scores are presented in Table XV. A calculated Z of 1.96 was required for significance at the .05 level.

The Z scores reveal that there is a significant difference between male and female values with respect to per cent fat and Astrand values. There was a significantly higher negative relationship between per cent fat and Astrand values for male subjects that for female subjects. There was also a significantly higher relationship between fat free body weight and Mitchell, Sproule and Chapman II results for female subjects than for male. Seventy decimal five six per cent of the variation in Mitchell, Sproule and Chapman II performance could be accredited to variations in fat free body weight in females while 57.76 per cent could be accredited to fat free body weight in males.

TABLE XV

Z SCORES FOR COMPARISONS OF THE RELATIONSHIP OF BODY COMPOSITION AND WORK CAPACITY FOR MEN AND WOMEN

Test	TBW	FFBW	% Fat
MSC2	.4831	2.3634*	1.4285
Astrand	.2415	.9033	2.2899*
Sjostrand I	.3151	1.9117	1.4285
Step I	1.5441	1.6281	1.3646

* Significance at the .05 level

Comparative Observations

Comparative observations were made between the data of this study and the data of other studies having a similar sample.

Maximal Oxygen Uptake. Table XVI presents the maximal oxygen uptake values obtained on this and other studies. The Mitchell, Sproule and Chapman test performed in this study evoked the highest maximal

oxygen uptake values (3.94 litres per minute) for males of those reported. Astrand's study, using highly trained women reports the highest maximal oxygen uptake values for women.

It is interesting to note the difference in maximal oxygen uptake obtained by the Astrand test and the Mitchell, Sproule and Chapman test reported in this study. This difference is in keeping with the results obtained by Glassford et al. (24) who found a maximal oxygen uptake for males of 3.485 litres per minute on the Astrand test and of 3.752 litres per minute on the Mitchell, Sproule and Chapman test.

TABLE XVI

MAXIMAL OXYGEN UPTAKE OBTAINED ON THIS AND OTHER STUDIES

Study	N	Age	Sex	MVO_2 (L./min)
Mitchell, Sproule and Chapman	65	20 - 29	M	3.37 ± .51
Buskirk and Taylor	59	18 - 29	M	3.44 ± .046
Glassford et al.	24		M	
(MSC)				3.752
(Astrand)				3.485
This Study	24	18 - 22	M	
(MSC)				3.94
(Astrand)				3.52
Michael and Horvath	30	17 - 22	F	1.78
Astrand	44	20 - 25	F	2.9 ± .04
This Study	24	17 - 20	F	
(MSC)				2.326
(Astrand)				2.118

Body Composition Estimates. Table XVII presents a comparison of estimates of fat free body weight, per cent fat and body density obtained on this and other studies.

TABLE XVII

BODY COMPOSITION ESTIMATES OBTAINED ON THIS AND OTHER STUDIES

Study	Sex	N	Age	FFBW(kg)	% Fat	Density
von Dobeln	M	35	19 - 40		10.6	1.072
- -	F	35	19 - 35		20.3	1.048
Sloan	M	50	18 - 26		10.8	1.075
Buskirk & Taylor	M	59	18 - 29		13.9	1.0632
Young et al	F	94	20.36 (mean)		28.69	1.0408
This Study	M	24	18 - 22	66.171	12.74	1.0704
	F	24	17 - 20	45.201	23.432	1.044

Maximal Oxygen Uptake and Body Composition. The correlations between estimates of body composition and maximal oxygen uptake for this study and others similar to it are presented in Table XVIII.

Because of the difference in maximal oxygen uptake values reported in this study between the Astrand and the Mitchell, Sproule and Chapman tests, there is a corresponding difference in the correlations between body composition estimates and maximal oxygen uptake values obtained on these tests.

The correlations between fat free body weight and maximal oxygen uptake for females as measured by the Mitchell, Sproule and Chapman II

test obtained in this study are high compared with those found by Darwick (17), however the correlations for females for total body weight and maximal oxygen uptake of this study are within the range of those found for the other studies reported. The values for male subjects appear reasonable in comparison with others.

TABLE XVIII

CORRELATIONS OF MAXIMAL OXYGEN UPTAKE AND BODY COMPOSITION OBTAINED ON THIS AND OTHER STUDIES

Study	Sex	N	Age	TBW	FFBW
Welch et al	M	26	24.9 $\pm$ 5.9	.59	.65
Buskirk and Taylor	M	59	18 - 29	.63	.85
Darwick	F	28	19 - 22	.64	.64
Seltzer	F	34	20 - 38	.88	
Michael and Horvath	F	30	17 - 22	.56	
Taylor	M	31	19 - 26	.43	
This Study	M	24	18 - 22		
MSC				.74	.76
Astrand				.61	.69
This Study	F	24	17 - 20		
MSC				.72	.84
Astrand				.59	.63

Submaximal Work Capacity and Body Composition. A comparison of the correlations between body composition and submaximal performance on this study and the studies of Taylor and Miller and Blyth are presented in Table XIX.

The subjects in the studies of Taylor, and Miller and Blyth performed submaximally on a treadmill while the subjects in this study performed on a bicycle and a stepping box. It is interesting to note the difference in the correlations obtained on the three pieces of apparatus.

TABLE XIX

CORRELATIONS OF SUBMAXIMAL WORK CAPACITY AND BODY COMPOSITION OBTAINED ON THIS AND OTHER STUDIES

Study	Sex	N	Age	TBW	FFBW
Miller and Blyth	M	30	19 - 28	.75	.67
Taylor	M	31	19 - 26	.71	
This Study	M	24	18 - 22		
(Sjostrand)				.46	.47
(Step)				.62	.56
This Study	F	24	17 - 20		
(Sjostrand)				.44	.60
(Step)		24		.52	.66

Discussion of the Relationship of Body Composition and Work Capacity

Maximal Work Capacity and Body Composition. Although the correlations of fat free body weight and maximal oxygen uptake are higher than those of total body weight and maximal oxygen uptake, these correlations have all attained significance at the .05 level for both male and female subjects. Following from these correlations, it seems that when the influence of body fat is removed, the relationship of the remaining fat free body and the ability of the body to do work does not change appreciably from the relationship when the fat was present. It appears therefore, that at maximal levels, the amount of fat in the body does not

influence significantly the ability of the body to do work. These findings are supported by the findings of Buskirk and Taylor (13) which state that "the presence of fat does not interfere with the overall maximal performance as measured by the maximal oxygen uptake test."

The maximal oxygen uptake is more a function of the ability of the cardiovascular-respiratory to supply oxygen to the tissues than it is of body composition.

Submaximal Work Capacity and Body Composition. For both male and female subjects on the Sjostrand test, there is no significant difference in the relationship of total body weight and PWC 170 (.46, .47 respectively) and fat free body weight and PWC 170 (.44, .60) at the .05 level. It appears that on the Sjostrand test, the relationship of body composition and PWC 170 does not change significantly whether fat is included in the calculations or not, thus indicating that the amount of fat does not influence significantly the ability to perform on this test.

The resulting correlations between body composition and step test scores for male and female subjects show no significant difference between the relationship of PWC 170 and total body weight and PWC 170 and fat free body weight thus indicating that when the effect of the amount of fat within the body is removed, the body performs on the step test no better than when the effect of the amount of fat was present.

Other studies (47, 52) have indicated that submaximal exercise is chiefly a function of body weight rather than fat free body weight. This study, however, has shown no significant difference in the relationship. The step test results show a trend towards a higher relationship between PWC 170 and total body weight for male subjects but this trend is not statistically significant.

For both male and female subjects, the correlations of the step test results and body composition are higher than the correlations of the Sjostrand test and body composition. It would seem that body composition has a greater effect on step test results than on Sjostrand results. At the maximal level, the correlations of body composition and the Mitchell, Sproule and Chapman results are higher than those of the Astrand results and body composition. At both maximal and submaximal levels of work, it seems that if the work involves lifting the body (as in the Mitchell, Sproule and Chapman test and the Step test) then the composition of the body performing the work plays a greater part than if the body weight is not lifted (as in the Sjostrand and Astrand tests).

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to investigate the relationship of estimates of body composition and measures of maximal and submaximal work capacity. The subjects, twenty-four female and twenty-four male students enrolled in the first year Physical Education and Recreation professional programs at the University of Alberta, were selected at random and performed four tests of work capacity - the Mitchell, Sproule and Chapman test, the Astrand test, the Sjostrand PWC 170 test and the Gradational Step test. Body composition was estimated by the densitometric method. Subsidiary problems investigated the difference in male and female subjects with respect to the relationship of body composition and work capacity.

Pearson Product-Moment correlation coefficients were calculated between each of the work capacity measures and body composition estimates and were tested for significance at the .05 level. In all tests for both male and female subjects, there was a significant relationship between the scores of the respective tests and both total body weight and fat free body weight.

The results of each test of work capacity were correlated with both total body weight and fat free body weight and the correlations tested for significance of difference at the .05 level. There was no significant difference in the correlations of fat free body weight and total body weight for either females or males with any of the tests of work capacity.

Conclusions

Within the limitations of the study, the statistical results lead to the following conclusions:

1. For female subjects, there was a significant correlation between

(a) Total body weight and work capacity as measured by the Mitchell, Sproule and Chapman test, the Astrand test, the Sjostrand test and the Gradational Step test.

(b) Fat free body weight and work capacity as measured by the Mitchell, Sproule and Chapman test, the Astrand test, the Sjostrand test and the Gradational Step test.

(c) Per cent fat and work capacity, as measured by the Sjostrand test and the Step test.

2. For male subjects, there was a significant correlation between

(a) Total body weight and work capacity as measured by the Mitchell, Sproule and Chapman test, the Astrand test, the Sjostrand test and the Gradational Step test.

(b) Fat free body weight and work capacity as measured by the Mitchell, Sproule and Chapman test, the Astrand test, the Sjostrand test and the Gradational Step test.

(c) Per cent fat and work capacity as measured by the Astrand and the Sjostrand test.

3. There was a significant difference between male and female subjects with respect to the relationship of per cent fat and the Astrand test values and fat free body weight and Mitchell, Sproule and Chapman values at the .05 level of significance.

4. There was no significant difference in the relationship of work capacity and total body weight and work capacity and fat free body weight for either male or female subjects in any of the tests of work capacity.

General Conclusion

On the basis of this study, it may be concluded that work capacity expressed per kilogram of total body weight is probably as good a reference standard as work capacity per kilogram of fat free body weight.

Recommendations

1. Residual volume should be measured directly in order to eliminate one source of error.

2. The reliability of the underwater weighing apparatus should be included in the study.

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APPENDICES

APPENDIX A

RAW DATA FOR WORK CAPACITY TESTS AND BODY COMPOSITION ESTIMATES

TABLE XX

RAW DATA FOR MAXIMAL OXYGEN UPTAKE TESTS
FOR FEMALE SUBJECTS

Subject Number	MSC I (l. of O_2)	MSC II (l. of O_2)	MSC MEAN (l. of O_2)	ASTRAND (l. of O_2)
1	2.003	1.802	1.902	1.814
2	1.855	1.658	1.756	1.503
3	2.252	2.251	2.251	2.175
4	2.323	2.576	2.450	2.314
5	2.198	2.644	2.421	2.157
6	2.143	2.265	2.204	2.196
7	2.225	2.409	2.317	1.684
8	1.893	2.245	2.069	1.769
9	3.120	3.082	3.101	2.843
10	2.351	1.983	2.167	1.920
11	2.276	2.340	2.308	1.958
12	2.363	2.301	2.332	1.900
13	2.516	2.434	2.475	2.228
14	2.346	2.241	3.294	2.073
15	2.439	2.517	2.478	2.466
16	1.419	1.630	1.524	1.172
17	2.675	2.563	2.619	2.281
18	3.401	3.002	3.202	2.682
19	2.224	2.691	2.157	2.024
20	2.287	2.102	2.194	2.327
21	2.969	3.249	3.109	2.933
22	2.050	2.480	2.265	2.276
23	2.660	2.172	2.416	2.490
24	1.571	1.776	1.673	1.655

TABLE XXI

RAW DATA FOR MAXIMAL OXYGEN UPTAKE TESTS FOR MALE SUBJECTS

Subject Number	MSC I (l. of O_2)	MSC II (l. of O_2)	MSC MEAN (l. of O_2)	ASTRAND (l. of O_2)
25	3.844	3.863	3.854	3.468
26	3.384	3.132	3.258	3.489
27	2.875	2.816	2.846	2.062
28	4.592	4.183	4.388	4.103
29	3.879	3.483	3.681	3.686
30	4.911	5.508	5.210	5.105
31	4.075	3.843	3.959	2.933
32	3.376	3.233	3.305	3.209
33	3.976	3.897	3.937	3.581
34	3.667	3.728	3.698	3.245
35	3.665	3.864	3.765	3.546
36	4.744	4.882	4.813	4.260
37	4.147	4.209	4.178	3.451
38	4.616	4.723	4.670	4.312
39	3.479	3.427	3.453	3.235
40	3.804	4.117	3.691	3.807
41	4.555	4.540	4.548	3.619
42	3.811	3.496	3.654	3.069
43	4.348	4.272	4.310	3.544
44	3.803	3.575	3.689	3.205
45	2.795	2.970	2.883	2.517
46	3.439	3.636	3.538	3.354
47	3.696	4.666	4.181	4.068
48	4.247	4.441	4.344	3.681

TABLE XXII

RAW DATA FOR PWC 170 FOR FEMALE SUBJECTS

Subject Number	Step I KgM	Step II KgM	Step Mean KgM	Sjost.I KpM	Sjost.II KpM	Sjost. Mean KpM
1	415.252	494.681	454.967	670.684	715.084	692.884
2	358.326	341.355	349.841	533.089	555.592	544.341
3	340.614	359.832	350.223	628.794	740.885	684.840
4	516.336	509.737	513.037	648.35	847.141	747.746
5	369.681	352.615	361.147	729.870	676.336	703.103
6	454.297	456.735	455.516	672.423	591.966	632.195
7	391.492	408.713	400.103	670.185	712.87	691.528
8	501.574	637.135	569.354	948.955	811.742	880.349
9	678.827	613.169	645.996	1072.915	900.182	986.549
10	476.375	447.409	461.892	619.987	644.166	632.077
11	650.525	635.895	643.210	907.987	1217.177	1062.582
12	465.149	458.662	461.905	819.340	664.839	742.090
13	528.514	530.163	529.338	578.975	814.127	696.551
14	345.566	286.919	316.243	744.203	645.377	694.790
15	556.808	539.910	548.359	981.667	935.667	958.667
16	347.289	299.818	322.801	449.232	451.806	460.516
17	637.875	683.293	660.559	965.002	884.840	924.921
18	577.708	647.523	612.616	914.170	851.650	882.91
19	468.622	448.317	548.469	624.213	571.670	597.942
20	413.054	383.705	398.379	649.326	650.430	649.878
21	588.724	563.531	576.128	924.304	1052.088	988.196
22	706.246	624.382	665.314	964.078	966.077	967.578
23	447.607	510.669	479.140	875.486	827.293	851.390
24	469.790	471.378	484.034	764.984	814.986	789.985

TABLE XXIII

RAW DATA FOR PWC 170 FOR MALE SUBJECTS

Subject Number	Step I KgM	Step II KgM	Step Mean KgM	Sjost.I KpM	Sjost.II KpM	Sjost. Mean KpM
25	873.068	780.174	826.621	1424.263	1354.632	1389.448
26	1009.905	1246.099	1128.002	1489.636	1417.213	1453.425
27	534.608	533.357	533.983	818.542	738.717	778.630
28	677.202	742.379	709.791	1234.220	1351.032	1292.626
29	833.135	785.793	809.464	1483.641	1485.184	1484.413
30	1241.060	1050.152	963.088	1736.324	1648.969	1692.647
31	788.184	741.584	764.884	903.530	983.546	943.538
32	942.616	809.937	876.277	1255.627	1306.237	1280.932
33	761.261	732.788	747.025	1319.430	1333.386	1326.408
34	684.497	628.989	656.723	1103.823	1218.687	1161.255
35	691.403	629.689	660.546	1067.567	940.036	1003.802
36	827.208	843.519	835.364	1249.758	1250.72	1250.239
37	1087.439	985.263	1036.351	1806.684	1652.876	1729.780
38	848.043	870.879	888.190	1547.559	1606.546	1577.053
39	960.186	1080.316	1020.151	1448.189	1368.046	1408.118
40	931.376	964.733	948.054	1449.409	1400.679	1425.044
41	911.064	921.217	916.141	1606.773	1636.755	1621.764
42	934.722	728.220	831.471	1214.341	1263.961	1234.131
43	828.907	965.253	897.080	2011.415	1521.31	1766.363
44	919.757	913.191	916.474	1536.323	1483.808	1510.066
45	713.916	649.725	681.820	1034.002	971.737	1002.870
46	824.746	632.200	728.473	903.344	945.642	924.493
47	1397.852	1201.217	1299.535	1611.965	1575.395	1593.68
48	1038.305	1099.026	1068.665	1546.210	1307.646	1426.928

TABLE XXIV

RAW DATA ON FEMALE BODY COMPOSITION
IN POUNDS

Subject Number	Dry Weight (lb.)	Fat Free Weight (lb.)	% Fat	Fat Weight
1	111.25	80.5450	21.60	30.705
2	117.50	91.815	21.86	25.686
3	122.75	92.836	24.37	29.915
4	138.00	112.898	18.19	25.102
5	138.00	104.714	24.12	33.286
6	128.75	95.301	25.98	33.449
7	150.00	111.735	25.51	38.265
8	128.00	92.672	27.60	35.328
9	150.50	121.273	19.42	29.227
10	116.70	83.441	28.50	33.295
11	148.00	110.674	25.22	37.326
12	129.50	105.141	18.81	24.359
13	143.50	110.151	23.24	33.349
14	114.75	91.284	20.45	23.466
15	125.00	102.313	18.15	22.688
16	107.50	78.014	27.26	29.236
17	136.25	111.412	18.23	24.838
18	135.75	107.569	21.91	30.181
19	127.25	86.645	31.91	40.605
20	142.50	92.290	33.13	47.210
21	141.75	113.811	19.71	27.939
22	137.25	109.128	20.49	28.123
23	135.00	96.120	28.80	38.880
24	109.25	89.683	17.91	19.567

TABLE XXV

RAW DATA ON MALE BODY COMPOSITION
IN POUNDS

Subject Number	Dry Weight (lb.)	Fat Free Weight (lb.)	% Fat	Fat Weight (lb.)
25	187.75	154.749	17.58	33.007
26	161.75	139.849	13.54	21.901
27	136.00	114.022	16.16	21.978
28	172.00	149.894	9.06	22.106
29	160.00	148.433	7.23	11.568
30	188.30	177.981	5.48	10.319
31	193.50	166.991	13.70	26.510
32	142.20	128.648	9.53	13.552
33	144.00	122.889	14.66	21.110
34	147.50	119.637	18.89	27.863
35	165.80	149.353	9.92	16.448
36	178.00	149.965	15.75	28.035
37	191.00	176.675	7.50	14.325
38	179.5	169.933	5.33	9.567
39	151.00	132.850	12.02	18.150
40	171.50	153.801	10.32	17.699
41	175.75	156.436	10.99	19.314
42	158.75	131.877	13.02	26.873
43	166.75	140.153	15.95	26.597
44	167.00	137.575	17.62	29.425
45	131.00	109.149	16.68	25.851
46	161.75	145.947	9.77	15.803
47	204.00	160.242	21.45	43.758
48	185.50	164.087	13.70	21.414

TABLE XXVI

BODY COMPOSITION OF FEMALE SUBJECTS
IN KILOGRAMS

Subject	Total Body Weight	Fat Free Body Weight	Fat Weight
1	50.463	36.534	13.928
2	53.298	41.647	11.651
3	55.679	42.110	13.569
4	62.596	51.210	11.386
5	62.596	47.498	15.098
6	58.401	43.228	15.172
7	68.040	50.683	17.357
8	58.060	42.036	15.117
9	68.266	55.009	13.257
10	52.935	37.849	15.103
11	67.132	50.189	16.931
12	58.741	47.692	11.049
13	65.091	44.964	15.127
14	52.050	41.406	10.644
15	56.695	46.409	10.291
16	48.762	35.387	13.261
17	61.803	50.536	11.266
18	61.576	48.793	13.690
19	57.702	39.302	18.418
20	64.638	41.862	21.414
21	64.297	51.624	12.673
22	62.256	49.569	12.757
23	61.236	43.600	17.636
24	49.555	40.680	8.755

TABLE XXVII

BODY COMPOSITION OF MALE SUBJECTS
IN KILOGRAMS

Subject Number	Total Body Weight	Fat Free Body Weight	Fat Weight
25	85.163	70.194	14.972
26	73.369	63.435	9.934
27	61.689	51.720	9.461
28	78.019	67.626	10.027
29	72.576	67.329	5.247
30	85.412	80.732	4.681
31	87.771	75.742	12.025
32	64.501	58.354	6.147
33	65.318	55.742	9.575
34	66.906	54.267	12.639
35	72.206	67.746	7.461
36	80.740	68.024	12.717
37	86.637	80.139	6.498
38	81.421	77.081	4.340
39	68.493	60.260	8.233
40	77.792	69.764	8.028
41	79.720	70.959	8.761
42	72.009	59.819	12.190
43	75.6373	63.573	12.064
44	75.751	62.404	13.347
45	59.4212	49.510	11.726
46	73.369	66.201	7.168
47	92.534	72.685	19.848
48	84.142	74.429	9.713

TABLE XXVIII

MEASUREMENTS INVOLVED IN UNDERWATER WEIGHING - FEMALE

Subject Number	Vital Capacity (l.)	Residual Volume (l.)	Body Density	Underwater Weight
1	3.0	.75	1.0344	1.750
2	3.8	.95	1.0480	5.000
3	3.1	.775	1.0420	3.500
4	3.5	.875	1.0569	2.125
5	2.9	.725	1.0426	2.250
6	2.3	.575	1.0382	1.500
7	3.4	.844	1.0392	3.500
8	2.8	.700	1.0344	3.375
9	3.7	.913	1.0539	2.125
10	2.3	.575	1.0323	2.500
11	3.8	.950	1.0400	4.500
12	3.8	.950	1.0554	3.500
13	3.5	.875	1.0447	3.250
14	3.98	.995	1.0514	5.250
15	4.1	1.025	1.0570	4.375
16	3.5	.875	1.0352	5.875
17	3.3	.825	1.0568	1.500
18	3.5	.875	1.0479	3.250
19	2.2	.55	1.0244	2.750
20	3.3	.813	1.0216	5.625
21	4.5	1.125	1.0532	5.000
22	3.9	.975	1.0513	3.875
23	3.1	.775	1.0316	4.125
24	3.3	.825	1.0576	3.000

TABLE XXIX

MEASUREMENTS INVOLVED IN UNDERWATER WEIGHING - MALE

Subject Number	Vital Capacity (l.)	Residual Volume (l.)	Underwater Weight (lb)	Body Density
25	5.4	1.350	4.250	1.0584
26	5.5	1.375	4.725	1.0684
27	3.0	.750	.250	1.0619
28	5.15	1.288	.125	1.0797
29	5.5	1.375	2.625	1.0844
30	5.5	1.375	- .375	1.0889
31	6.3	1.575	4.875	1.0680
32	4.3	1.075	1.250	1.0785
33	4.8	1.200	4.125	1.0656
34	3.5	.875	1.625	1.0552
35	4.9	1.225	1.250	1.0775
36	4.5	1.113	1.250	1.0629
37	5.6	1.400	.375	1.0837
38	5.1	1.263	-1.250	1.0893
39	5.3	1.325	4.125	1.0722
40	5.7	1.425	3.125	1.0765
41	5.5	1.375	2.500	1.0748
42	4.7	1.163	2.375	1.0697
43	4.8	1.200	3.125	1.0624
44	4.2	1.050	2.000	1.0583
45	3.3	.825	1.375	1.0606
46	4.5	1.125	.375	1.0779
47	4.2	1.050	1.500	1.0490
48	4.9	1.213	1.375	1.0680

APPENDIX B

STATISTICAL TECHNIQUES

STATISTICAL TECHNIQUES

Computation of the Mean (21:46)

$$\bar{X} = \frac{\sum x}{N}$$

$\bar{X}$ = mean

x = the sum of the values of x

N = the number of scores

Computation of the Standard Deviation (21:66)

$$s = \sqrt{\frac{\sum(x - \bar{X})^2}{N - 1}}$$

s = the standard deviation

Computation of the Correlation Coefficients (21:111)

$$r = \frac{N\sum XY - \sum x \sum Y}{\sqrt{\left[N\sum x^2 - (\sum x)^2\right]\left[N\sum Y^2 - (\sum Y)^2\right]}}$$

r = correlation coefficient

N = number of paired observations

X = the sum of the values of X

Y = the sum of the values of Y

Significance of a Correlation Coefficient (21:186)

$$t = r\sqrt{\frac{N - 2}{1 - r^2}}$$

N = the number of paired observations

Significance of the Difference of Correlation Coefficients - Independent Samples (21:189)

$$z = \frac{Z_{r_1} - Z_{r_2}}{\sqrt{1/(N_1 - 3) + 1/(N_2 - 3)}}$$

Significance of the difference of Correlation Coefficients - Correlated Samples (21:186)

$$t = \frac{(r_{12} - r_{23})\sqrt{(N - 3)(1 + r_{23})}}{\sqrt{2(1 - r_{12}^2 - r_{13}^2 - r_{23}^2 + 2r_{12}r_{23}r_{13})}}$$

RELIABILITY AND VALIDITY OF THE WORK CAPACITY TESTS
FOR FEMALE SUBJECTS

MSC	MSC$_1$	MSC$_2$	AST.	SJOST.	SJOST$_1$	SJOST$_2$	STEP	STEP$_1$	STEP$_2$
	.959	.952	.900	.631	.632	.547	.304	.299	.273
		.826		.536	.552	.449	.273	.246	.279
				.675	.659	.602	.310	.319	.282
				.626			.324		
					.933	.936	.720	.700	.690
						.746	.691	.663	.671
							.654	.646	.619
							.961		.846
							.969		

RELIABILITY AND VALIDITY OF THE WORK CAPACITY TESTS
FOR MALE SUBJECTS

MSC	MSC_1	MSC_2	AST.	SJOST	$SJOST_1$	$SJOST_2$	STEP	$STEP_1$	$STEP_2$
	.96	.97		.60	.55	.61	.002	.004	.0
		.88		.58	.53	.61	-.06	-.09	-.03
				.58	.54	.59	.06	.09	.02
.87	.80	.87		.62	.56	.67	.23	.24	.20
					.98	.97	.58	.5	.58
						.91	.58	.48	.59
							.56	.51	.54
								.92	.94
									.75

APPENDIX C

SAMPLE CALCULATION SHEETS

MITCHELL, SPROULE & CHAPMAN TEST

HEART RATE

NAME: ____________________

DATE: ____________________

RESTING HEART RATE: ____________________

TREADMILL %	HEART RATE

MAXIMAL O_2 CONSUMPTION: ____________________ l./min.

COMMENTS:

ASTRAND BICYCLE ERGOMETER TEST

NAME: ______________________________

DATE: ______________________________

RESTING HEART RATE: ______________

KPM	HEART RATE
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________

MAXIMAL O_2 CONSUMPTION ____________ l./min.

COMMENTS:

SJOSTRAND PWC_{170} TEST

NAME: ______________________

DATE: ______________________

RESTING HEART RATE: ______________________

	TIME								
	1		2		3		4		
Work Load	HR	RPM	HR	RPM	HR	RPM	HR	RPM	STEADY STATE

ROOM TEMP.: ______________________

BAROMETRIC PRESSURE: ______________________

COMMENTS:

GRADATIONAL PWC_{170} STEP TEST

NAME: ______________________________

DATE: ______________________________

RESTING HEART RATE: ______________________

TIME

STEP HEIGHT	1	2	3	4	STEADY STATE

ROOM TEMP.: ____________________

BAROMETRIC PRESSURE: ______________

COMMENTS:

ESTIMATION OF BODY COMPOSITION

NAME: ______________________________

DATE: ______________________________

BODY DENSITY MEASUREMENTS

Weight on land	=	______ lb.
Apparent Weight in Water-Full Inspiration	=	______ lb.
Weight of Apparatus	=	______ lb.
Actual Weight in Water-Full Inspiration	=	______ lb.
Vital Capacity	=	______ cu.in.
Residual Volume	=	______ cu.in.

Total Lung Capacity =

(VC) ________ +(RV) ________ +(V.GI.) _____ X.0362 = ______ lb.

True Weight in Water ______________ + ______________ = ______ lb.

Body Volume = Wt. in air - true wt. in water = ______

$$\text{Body Density} = \frac{\text{Wt. in air}}{\text{body volume}} \times \text{density of water}$$

= ______________ X __________________ = ______

Calculations of Body Fat

$$\text{Total Fat} = \frac{4.570}{\text{body density}} - 4.142$$

Total Fat = 4.570 - 4.142 = ______

% Body Fat = ______ %

Fat Weight of Body = ______ LB.

Fat Free Weight = ____________ - ____________ = ______ lb.